

The Potential Effects of Acid Deposition: What's a National Forest to Do?

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The mid-Atlantic region, in which the Monongahela National Forest lies, receives some of the highest rates of acidic deposition in the country. As a result of the substantial acidic inputs and growing public concern with the problem, the forest is addressing this topic in its current forest plan revision as it relates to potential effects to water quality, aquatic habitat, soil nutrient status, and forest productivity. Plan revision is approximately fifty percent complete, and the revision team is now in the initial stages of designing a multi-level monitoring plan to collect and compile data to evaluate short- and long-term effects of continued deposition and land management activities on soil and water resources. This paper briefly describes the state of the science of acidic deposition effects on land productivity, and their management implications for the Monongahela. Additionally, risk assessment analyses for the forest and monitoring strategies to continue data collection and database expansion are described. Preliminary soil chemistry data from watersheds highly sensitive to acidic inputs and base cation loss on the Monongahela National Forest are presented to illustrate the importance of including this problem in forest plan revision and project level planning, and to show how the team incorporated available data in its decision processes.

Keywords: *acid precipitation, air pollution, calcium, soil productivity, resource management*

AN INTRODUCTION TO ACIDIC DEPOSITION AND ITS EFFECTS

Acid deposition occurs when sulfur dioxide and nitrogen oxides react with water and oxygen in the atmosphere to form acidic compounds, which then fall to earth in either a dry or wet form (EPA 1998). The northern half of West Virginia has long been recognized as an area of high acid deposition. Total annual sulfur deposition on the Monongahela National Forest in the late 1980s ranged from 19 kg/ha at the lower elevations, to 26 kg/ha at high elevations (Adams et al. 1991). Few areas of the United States showed higher sulfur deposition than was found on the Forest. Current monitoring results show that wet sulfate deposition has decreased 29 percent in the mid-Atlantic region as the Acid Rain Program emission reductions have been implemented (EPA 2004). In fact sulfur deposition at Parsons, West Virginia (a lower elevation monitoring site) was down to 12 kg/ha in 2000 ([http://](http://www.epa.gov/castnet/charts/par107ts.gif)

www.epa.gov/castnet/charts/par107ts.gif, accessed February 2006).

Bases, such as calcium and magnesium, are also found in atmospheric deposition, and these compounds could help offset some of the negative effects of acid deposition. However concentrations of bases in atmospheric deposition have also decreased. For example, at Parsons, West Virginia, annual calcium deposition has decreased from about 4 kg/ha in 1979 to just over 1 kg/ha in 2003 (<http://nadp.sws.uiuc.edu/trends/trendRequest.asp?site=WV18>, accessed February 2006).

Soil acidification can be seen as a balance between acid inputs and mineral weathering (Binkley et al. 1989). Therefore, when soil acidifying processes (such as acid deposition and forest growth) exceed mineral weathering inputs of base cations, acidification occurs.

Changes in soil chemistry are difficult to quantify due to the long periods of time over which they occur, the complexity of the factors controlling them (Markewitz et al. 1998), and the inherent spatial heterogeneity of soils. A study of soil acidification in the Calhoun Experimental Forest in South Carolina using soil data from 1962 to

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1990 showed that the upper 60 cm of soil acidified at an accelerated rate due to acidic deposition while the naturally acidifying processes of biomass accumulation, root and microbial respiration, and organic matter incorporation also occurred (Markewitz et al. 1998).

Soil acidification increases cation leaching, decreases soil pH and base saturation, increases the N content of trees, and negatively affects many biological processes (Adams and Kochenderfer 1999). Adams (1999) found that Ca losses were particularly large when a forest soil becomes acidified. A nine-year acidification study at Bear Brook watershed in Maine showed accelerated loss of base cations from the soil, which subsequently leached into streams (Fernandez et al. 2003). Base cations also are removed from the soil by plant uptake, leaching, and harvesting (Gbondo-Tugbawa and Driscoll 2003).

The major base cations in atmospheric deposition, soils, and geologic materials are Ca^{+2} , Mg^{+2} , Na^{+} , and K^{+} . Of these Ca and Mg typically provide the greatest contribution to buffering because they usually are more abundant than K and Na and they possess a greater positive charge. Mineral weathering of soil and geologic materials control base cation availability over the long term, but the major short-term sources of base cations to soil are litter fall and atmospheric deposition (Johnson and Todd 1990; Jenkins 2002). Slope position affects base cation supplies because litter accumulates more on lower slope positions than on higher ones (Johnson and Todd 1990).

The National Acid Precipitation Assessment Program (NAPAP 1998) indicated that base cation depletion may affect the health of forest ecosystems. The health of eastern hardwood forests has not yet shown adverse effects from acid deposition on a broad scale (NAPAP 1998). However, mortality and decline of red spruce (*Picea rubens*) at high elevations in the Northeast have been significant and provide the greatest evidence of forest damage by acidic deposition (NAPAP 1998). Sugar maple (*Acer saccharum*) is also a species of concern (Likens et al. 1996; Bailey et al. 2005), since it is particularly sensitive to decreases in Ca and Mg soil pools.

EXISTING CONDITIONS ON THE MONONGAHELA NATIONAL FOREST

Aquatic Resources

The Monongahela National Forest (MNF) is the fourth largest national forest in the northeast and contains the headwaters of five major river systems: the Monongahela, Potomac, Greenbrier, Elk, and Gauley Rivers. Twelve river segments on the MNF are being studied for potential classification in the National Wild and Scenic Rivers

System. Rivers and streams across the forest include more than 900 km of coldwater trout streams and provide an additional 200 km of warm water fishing. Although the State of West Virginia manages many stream segments as put-and-take trout fisheries with seasonal trout stocking, some estimates suggest 90% of West Virginia's native brook trout (*Salvelinus fontinalis*) streams occur on the MNF.

Healthy, reproducing trout populations and their associated communities have various habitat requirements. Water quality in rivers and streams is an important consideration when establishing management priorities on the forest to provide for the maintenance of healthy aquatic ecosystems. Water chemistry is one component of water quality and represents a fundamental building block for aquatic communities. For example, harmful effects to certain aquatic organisms, such as reduced reproduction, begin to occur as pH values in streams fall below 6.0; detrimental effects, such as mortality, begin to occur as pH falls below 5.0. Also, values less than 50 for acid neutralizing capacity (ANC) indicate a stream system is acid sensitive, values less than 25 suggest a system likely experiences episodic acidification during storms, and negative ANC values indicate a system is already acidic (<http://www.dep.state.wv.us>).

Water chemistry of streams and rivers is the by-product of dynamic nutrient pathways and chemical processes occurring within the contributing watershed environment-atmospheric, terrestrial, and biological. The significance of water chemistry is perhaps no more apparent than in aquatic ecosystems composed of diverse geology, particularly when these systems are exposed to acid deposition. Watersheds across the MNF exhibit a wide range of surficial geologies that have variable capacities for neutralizing acid inputs.

In 2001, the MNF initiated an effort to establish forest-wide monitoring of water chemistry properties in streams across the forest. Sample sites were strategically located to allow monitoring efforts to increase the level of understanding of the relationships between water chemistry and various local environmental factors including the geologic composition of contributing watershed areas, rates of acid deposition, and supported aquatic communities. Results of water chemistry monitoring from fall low flow and spring high flow sampling demonstrated a high degree of variability between sample locations and sample periods, as expected. For example, measures of pH ranged from 3.88 to 8.2 (mean = 6.8) during fall 2001 samples (low flow conditions) and from 3.73 to 8.55 (mean = 6.4) during spring 2002 samples (high flow conditions). Measures of ANC ranged from -166 to 2868 (mean = 407) during fall 2001 samples and from -195 to 1599 (mean = 135) during spring 2002 samples.

Variation in measures of pH and ANC between sample locations was largely explained by the variable capacity of a watershed's geology to neutralize acid inputs. Variation in measures of pH and ANC between sample periods at a given site was largely explained by the different stream discharge conditions. Except where acid mine drainage is an issue, water samples collected at low flow conditions during the late summer to early fall period are typically expected to exhibit higher pH and ANC values due to the greater influence of groundwater on stream flows, as compared to spring high flow conditions when direct inputs from melting snow and precipitation (i.e., acid rain) have greater influence.

State water quality monitoring programs are also documenting cases of stream acidification in West Virginia. In an attempt to mitigate impacts of stream acidification on native trout streams and the recreational fishing opportunities they provide, the state has developed and refined a program to treat acid impaired streams with limestone sand. Limestone sand is currently being applied to acid impaired streams on the forest and across the state to help neutralize acidity. Forest monitoring results show water chemistry downstream from treatment areas exhibits notable increases in ANC, pH, and Ca when compared to untreated water upstream. Although this action helps mitigate against many symptoms of stream acidification within the effective stream treatment zone, it does not affect the underlying cause of the condition to address risks to aquatic and terrestrial ecological processes and functions that extend beyond the treatment zones (McClurg et al. 2004).

Parent Materials

Soils of the MNF have developed from sedimentary rocks and are divided broadly into two zones that have different soil patterns, the Allegheny Plateau Province and the Appalachian Ridge and Valley Province. The Allegheny Plateau Province has relatively flat-lying bedrock. Soils on the Plateau are characterized by high moisture content, thick humus, acidic conditions, and low nutrient levels. Timber productivity in this region of the forest is more a function of soil moisture than fertility. In the Ridge and Valley Province, bedrock is folded, faulted, and fractured. Rock outcrops and escarpments are common. Soils are often shallow, shaley, droughty, and not highly productive. Most MNF soils exhibit moderate to severe erosion potential, and high hazard areas exist in areas of shale and limestone.

Elevation on the MNF ranges from 274 m to 1482 m. Rain shadow effects caused by slopes of the Allegheny Front result in an average of 153 cm of annual precipitation

on the west side of the MNF and about half that amount on the east side. Soils develop under mesic and frigid climatic temperature regimes where annual air temperature is 9°C. Frigid soil temperatures usually exist above 915 m. The mountainous landscapes on the MNF result in steeply sloping topography, with many areas having slopes of 30% or greater.

Soils on the MNF have been subject to the effects of abusive cutting and burning in the late 1800s and early 1900s. Logging without regard to resource protection contributed to damaging floods, severe erosion and topsoil loss, and pollution of streams. Severe fires further increased erosion by burning so hot that soil carbon was lost to the atmosphere. Soil productivity in some areas on the MNF is irretrievable in human time frames. Although there has been some recovery for the soil resource during the past century, many forest soils on the MNF still have only thin surface horizons, which now limit their ability to neutralize acidic inputs.

Air Quality

Historic atmospheric deposition, particularly of SO₄ (sulfate), from the Ohio River Valley and other Midwestern areas has contributed to acidification of streams and could affect soil productivity in parts of the MNF. Evidence of nutrient depletion in certain soils on the MNF has been found (Jenkins 2000; Schnably 2003; C. Sponaugle personal communication). Sulfate also is a primary contributor to visibility impairment or regional haze.

Sulfates are formed from atmospheric emissions of SO₂ (sulfur dioxide) from power plants and other industrial sources. The MNF receives industrial emissions primarily from sources in Ohio, Pennsylvania, Indiana, Illinois, and West Virginia. These states continue to produce some of the highest sulfur dioxide emissions in the nation, despite significant emissions reductions made during the 1990s. The combination of high emissions and limited buffering capacity of certain geologies and soils on the MNF have increased stream water acidity and possibly contributed to soil nutrient depletion.

The 1990 Clean Air Act Amendments (CAAA) Acid Rain provision mandated significant reductions in SO₂ emissions in the 1990s. The greatest percentage decreases in atmospheric SO₄ concentrations occurred in the eastern states north of Tennessee and North Carolina, and the highest absolute decrease (73%) occurred at the Bearden Knob air monitoring station on the MNF (often referred to as Dolly Sods in the literature) (Malm et al. 2000). These reductions are attributable to large reductions in SO₂ emission at sources upwind from the MNF (between 1990

and 1999: Indiana: -44%, Ohio: -35%, West Virginia: -34%, Kentucky: -29%, and Illinois: -13%). In these five states, SO₂ emissions decreased by 2.5 million tons between 1990 and 1999.

Downward trends in SO₂ emissions and SO₄ deposition will affect MNF resources positively; however, they may not be enough to reverse all of the degradation that already has occurred.

According to modeling projections made by the Southern Appalachian Mountains Initiative (2002), reductions in SO₂ emissions resulting from the 1990 CAAA will not be enough to restore the chemistry of acidified streams to levels where aquatic life can thrive. Additional emission reductions will be needed to restore acidified streams and natural atmospheric visibility conditions.

The Occurrence of Acid Conditions and Acid Sensitivity on the MNF

Soil water and stream acidification are real phenomena that have been shown to occur in West Virginia. Long-term, increasing losses of base cations to stream water due to ambient acid deposition have been documented in stream water on a control watershed in the Fernow Experimental Forest, which is located in the MNF (Edwards and Helvey 1991). Other watersheds on and near the Fernow Experimental Forest that have been artificially acidified with S and N to determine effects on soils and stream water have shown mobilization of base cations in soil and consequent leaching to stream water and substantial reductions in the acid-neutralizing capacity of soil water (Edwards et al. 2002a, 2002b).

Otter Creek Wilderness is one of the most popular recreation areas in the MNF, and because it also is designated a Class I area¹ it has been intensively monitored to characterize the extent of acidic water, soils, and geology. Approximately 71 percent of the Otter Creek Wilderness is underlain by geologic material of the Pennsylvanian Epoch. The dominant geology is the Pottsville Group, which generally has very acidic strata. Many of the sandstones associated with Pottsville geology are resistant

to weathering, and weathered materials produce very acidic soils with pH values ranging from 3.5 to 4.6. Only small base cation reserves exist to be weathered to the soil, so there is little to no acid-neutralizing capacity available (Jenkins 2002).

Total Ca and Mg levels measured in high-elevation soils underlain by Pennsylvanian geologic material in Otter Creek range from 513 to 1095 kg/ha and 3896 to 6662 kg/ha, respectively (Jenkins 2002). Total soil reserves of these base cations are much less than those in similar forest ecosystems. For example, Mann et al. (1988) and Federer et al. (1989) calculated average total stores of Ca in other Northeastern forest soils to be approximately 4 to 20 times greater than those in Otter Creek. Otter Creek soils also have elevated aluminum, which poses a threat to forest productivity and exacerbates soil nutrient deficiencies (Jenkins 2002). Jenkins (2002) found that most of the soils studied from Otter Creek have a Ca:Al molar ratio of less than 0.2 along with a base saturation of the effective cation exchange capacity (BSECEC) of less than 15%. This was interpreted to mean that these forests are at about a 100% risk for decline based upon work by Cronan and Grigal (1995). High Al concentrations are present in soils supporting declining spruce stands in northeastern United States and are commonly thought to inhibit Ca uptake and transport (Shortle and Smith 1988). Red spruce (*Picea rubens*) is a dominant tree species growing in the high elevation soils of Otter Creek Wilderness, and it is an important ecosystem component for several rare or listed species on the MNF.

While Otter Creek has been intensively monitored, more widespread continuous monitoring of soils around the MNF has taken place since before the 1970s through cooperative efforts between the USDA - Natural Resource Conservation Service (formally the USDA Soil Conservation Service) and the MNF to develop and publish county soil survey reports. While the data are not complete and the soil pits from which the data were obtained were not always located in areas of interest to the MNF, the soil data were collected across multiple geologies over time and are very useful in helping to assess soil productivity.

Since 2001, additional intensive soil data collection continues to be done outside of Otter Creek Wilderness to develop baseline soil chemistry data across the MNF, especially in areas assessed by the Soil Nutrient Sensitivity Map (described in the next section) to be highly sensitive to acidification. More than 500 soil samples have been collected across varying soil types, landscape positions, and varying aspects and analyzed for physical and chemical characteristics. Preliminary results show that soils in sensitive areas are affected adversely by acid deposition.

¹ The Clean Air Act Amendments (CAAA) of 1977 established the prevention of significant deterioration (PSD) program. These amendments designated specific Wildernesses and National Parks over a certain size as Class I areas. These federally mandated Class I areas are provided with an additional measure of protection under Title I, Part C of the CAAA, which states that one purpose of the Act is "to preserve, protect, and enhance the air quality in national parks, national wildernesses". Further more, the PSD regulations charge the federal land manager with the "affirmative responsibility to protect the air quality related values (including visibility) of any such lands," and to consider "whether a proposed source or modification would have an adverse impact on such values" (40 CFR 51.166 (p)(2)).

Base saturation values often are below 15 percent and Ca:Al ratios are less than 1.0 for soils found on ridgetops and benches. Some south-facing cove soils have soil Al levels that might indicate possible toxicity for vegetation. The data are just now becoming available and the interpretations should be ready for the 2006 forest-wide monitoring report.

APPROACHING ACIDIC DEPOSITION EFFECTS IN FOREST PLAN REVISION

Soil Nutrient Sensitivity

Acidic deposition and its effects on soil productivity arose as a new issue during the scoping phase of Forest Plan Revision in 2003. After a review of the literature, discussions with research scientists, and discussions with internal interdisciplinary team members, the issue was brought forward as a primary issue during Forest Plan Revision. Soil productivity issues and mitigations on disturbed lands were addressed in the Standards and Guidelines of the 1986 Monongahela National Forest Land Management Plan (USDA Forest Service, p. 79 and Appendix S), but there was no consideration of soil productivity losses caused by base cation depletion on undisturbed soils.

To address this issue in the forest plan revision, areas on the MNF susceptible to potential effects of acid deposition first were identified and mapped using a multi-step process. The initial map data layer in the analysis was the geology layer; geology was ranked as high, medium, or low sensitivity based on the geochemistry from county geology documents and personal knowledge of MNF geologists. Geology known to have substantial sources of alkalinity was assigned low sensitivity because it could provide a reasonable level of buffering capacity to soil. Geology known to have only trace amounts of alkaline producing minerals was rated as high sensitivity. Geology known to have a moderate amount of alkaline producing minerals or interbedded seams of calcite or alkaline shale received a rating of medium sensitivity due to the uncertainty about the amount of weatherable alkaline minerals or the depths of the material from the rooting zone.

The second map data layer included in the analysis was the stream layer of the MNF. Streams were analyzed for water quality impacts from acid rain and mine drainage using the current 303d listing from the state (<http://www.dep.state.wv.us>). Sources of acidity were identified in the stream layer. The correlation between geology and stream water quality is strong. Where high geologic sensitivity exists on the MNF, acid rain impaired streams

are present. Some streams flow through areas of low sensitivity but remain impaired due to the large effect from upstream geochemistry, soil chemistry, and precipitation chemistry.

The third map data layer was SO₄ deposition across the MNF. Deposition data were generated by Dr. James Lynch at The Pennsylvania State University. Areas of the MNF that received high amounts of wet SO₄ deposition rates were identified with this map layer (Figure 1). Other forms of SO₄ deposition also occur which are not depicted in this map, such as dry deposition and fog deposition. Some experts estimate that dry deposition may be at least as much as the wet deposition totals. Fog deposition is often not even accounted for in measurements and may be greatly underestimated at the higher elevations. Therefore, this map captures only a portion of actual deposition rates.

The combination of these three analysis layers provides an overall picture of acid deposition sensitivity across the MNF (Figure 2). In general, an area with highly sensitive geology, high rates of sulfate deposition, and acid rain impaired streams would indicate potential soil productivity problems in the surrounding watershed. An area with moderate sensitivity, high rate of sulfate deposition, and a non-acid impaired stream may indicate an area that may not be susceptible. However this area would require an assessment of any monitoring data and a site visit by a specialist. This acid deposition sensitivity layer (Soil Nutrient Sensitivity Map) is being used at the Forest Plan Revision level, the forest-wide level for analyses, and at the watershed assessment level.

Forest-wide Monitoring

While the Soil Nutrient Sensitivity Map provides a useful way to estimate a soil's sensitivity to acidic inputs or acid-causing situations (i.e., a risk assessment), the map does not provide a direct measure of soil productivity, which is very important for forest level management. Soil productivity can be predicted using available soil chemistry and acid deposition data. The MNF currently is deciding on the approach that it will take to assess soil productivity from a Forest Plan perspective. These decisions have not been finalized, but from the general direction of approach it now appears that following the initial risk assessment determined from the Soil Nutrient Sensitivity Map, specific chemical analyses of soil and water will be required for areas at high risk of nutrient depletion before management activities that might remove base cations are approved (e.g., timber harvesting or ground disturbance). Currently

Text continues on page 435.

Figure 1. Wet sulfate deposition levels across the Monongahela National Forest.

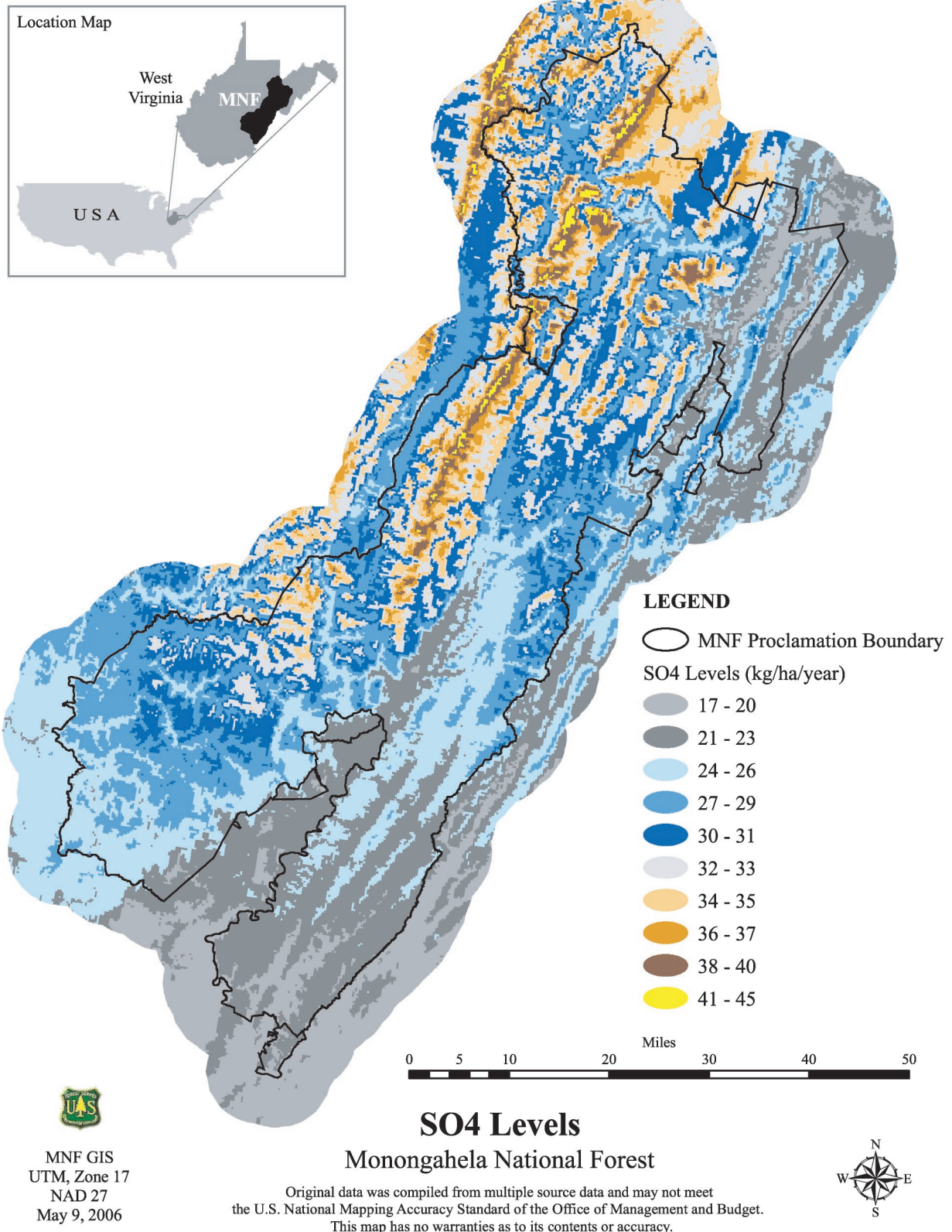
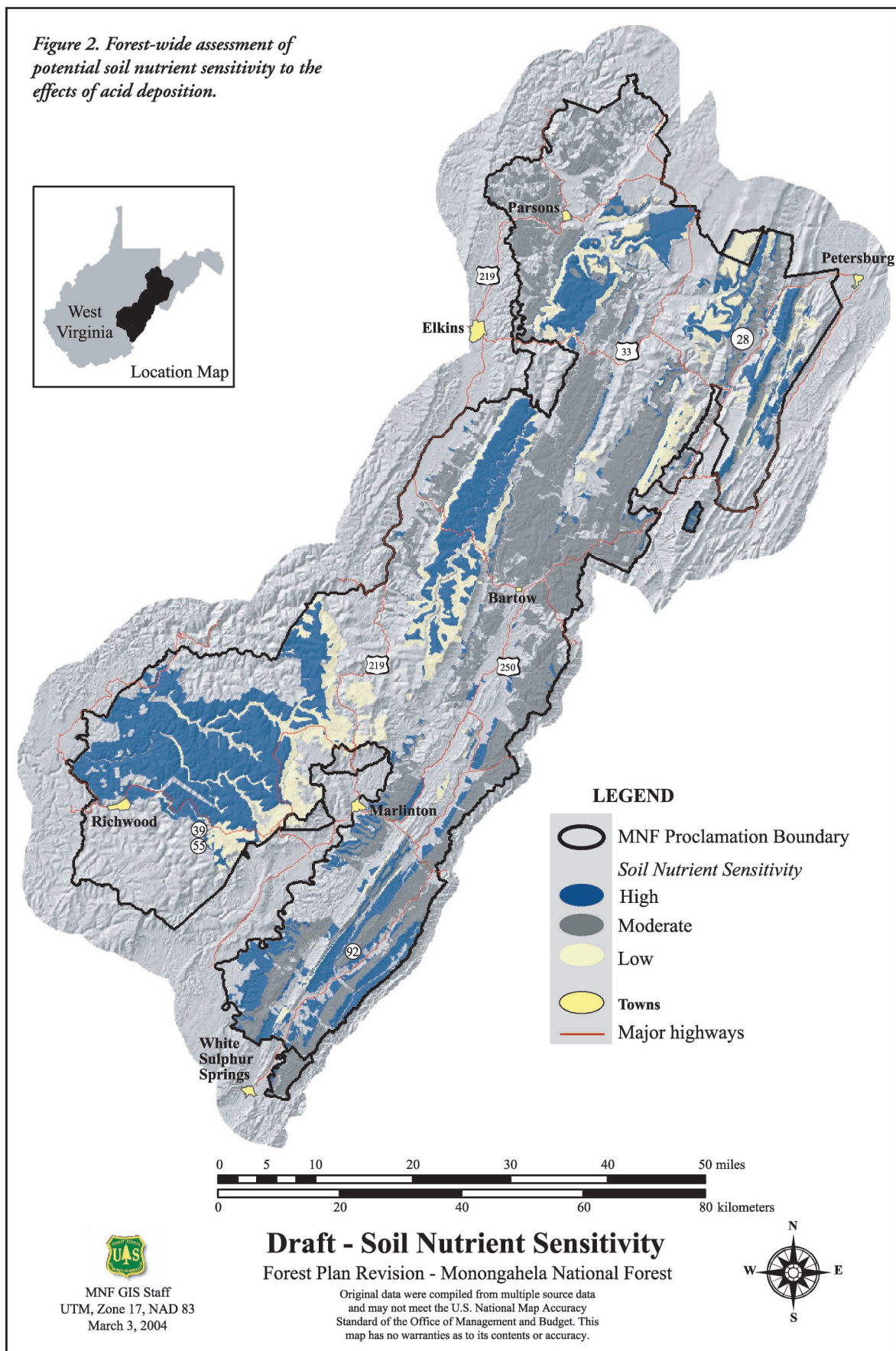


Figure 2. Forest-wide assessment of potential soil nutrient sensitivity to the effects of acid deposition.



the chemical criteria being considered for monitoring soil productivity of sensitive areas are: 1) soil Ca:Al ratios; 2) soil base saturation; 3) effective cation exchange capacity of the soil; 4) acid neutralizing capacity (ANC) of the stream water within subwatersheds (Hydrologic Unit Code [HUC] levels 6 and 7); and 5) the presence or absence of vegetative indicator species in the understory.

CRITICAL LOADS

Ultimately, the ability to calculate an array of critical loads with regard to acidic deposition and forest management alternatives is the goal that the MNF would like to achieve; critical loads provide quantitative answers to the "So what do soil conditions or acidity mean in terms of forest management?" question. A critical load is that amount of pollution below which no adverse impacts will occur. Currently, the MNF does not have all the necessary data to determine critical loads for the many combinations of deposition, geology, soil, and water chemical characteristics present on the MNF. Data collected within the MNF's various resource staff areas, routine monitoring programs, and data that will be collected as a result of the monitoring program set forth in Forest Plan Revision will be used to evaluate and refine current conditions using the Soil Nutrient Sensitivity Map and eventually to develop critical loads. The necessary stream, soil, and soil water data have been collected from a few sites on the MNF to calibrate the MAGIC Model (Model of Acidification of Groundwater in Catchments), which will be used to calculate critical loads. Determination of critical loads for the many types of sites on the MNF will provide a tool that land managers can use to better protect resources; land managers then can assess how various land management alternatives might affect desired future conditions based on an array of critical loads. At the regional or national scale, policy makers can use critical loads to determine what levels of pollutant reductions would be needed to achieve desired future conditions on larger landscape or at regional scales.

OTHER NATIONAL FORESTS IN REGION 9

Many forests in the northeastern portion of the eastern region of the US Forest Service (areas east of the Ohio River basin and northeast of the Great Lakes) are experiencing similar effects on resources from acid deposition. The White Mountain National Forest, in New Hampshire and Maine, has assessed resource effects of acid deposition and has developed a scientific approach to effects monitoring and management of those affected resources. Research at the Hubbard Brook Experimental Forest, located in the White Mountain National Forest, indicates that long-term

depletion of forest soil Ca could affect forest productivity, health, or composition, particularly of red spruce and sugar maple (Federer 1989). Currently, the Green Mountain National Forest in Vermont is assessing soil productivity in relationship to acid deposition sensitivity.

Studies on the Kane Experimental Forest and the Allegheny National Forest in northwestern Pennsylvania show that sugar maple is sensitive to soil Ca levels (Bailey et al. 2004; Horsely et al. 2000). Soils in this region have parent materials formed from the same Pottsville geologic formation underlying the Allegheny Plateau. These Pottsville-derived soils are naturally highly acidic and Ca deficient. In this area of Pennsylvania, Ca depletion has led to significant mortality of sugar maple in large areas when other pre-disposing factors, such as drought and insect infestation have been present and have served to exacerbate mortality.

CONCLUSION

Acid deposition is a real issue for the MNF. The relationships between air, water and soil chemistry are not always clear; however, science has shown links and associated effects. The results from forest stream monitoring sites are supported by the acid sensitive geology classification developed by combining data from the US Geological Survey with information on rates of acid deposition from the 2002 Southern Appalachian Mountain Initiative Report. That is, water chemistry monitoring on the forest indicates poor water chemistry buffering in aquatic systems located in contributing watershed areas dominated by geologies classified as higher acid sensitivity, and in some cases those systems dominated by a combination of moderate and higher acid sensitive geologies. Soil productivity monitoring is providing additional information, which will lead to the ability to model long-term cumulative effects in watersheds. This data will ultimately help land managers answer questions about the potential long-term effects of management activities in highly sensitive areas and the forest's ability to achieve future desired conditions.

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